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A QUANTITATIVE STUDY OF CERTAIN PERTHITIC FELDSPARS.

By Charles H. Warren.

(Continued from page 3 of cover.)

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Received, April 26, 1915.

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Introduction.— It is the chief purpose of this paper to present the results of a quantitative microscopic and chemical study of certain perthitic feldspars from granite pegmatites.

The feldspars here considered are all from granite pegmatites from widely separated localities. They show a considerable range in the relative proportions of the two feldspar phases present, and were found upon examination to be satisfactorily free from foreign inclusions and from alteration. The number of specimens originally chosen for study was ten. Of these four were unfortunately sent to Europe during the early summer of 1914 for sectioning and have been held there because of the war, so that the results of the investigation can not, at this time, be made quite as comprehensive as was originally planned. However, as it is believed to be unlikely that the results obtained from the study of these four feldspars would have materially modified those obtained from the six remaining preparations, plus the two studied by Mäkinen, and here included, it has

been thought best to put on record the results of the investigation as it stands.

In recent years J. H. L. Vogt [1] has given us in an elaborate and suggestive paper, an hypothesis regarding the physico-chemical relations of the alkali-feldspars. He has not, so far as the writer is aware, furnished us with a detailed quantitative microscopic and chemical study combined of particular feldspar intergrowths such as is here described. In an admirable paper on the Granite Pegmatites of Tammela in Finland, Eero Mäkinen [2] has given us a careful chemical and microscopic study of certain perthites from some of the Tammela pegmatites, including a quantitative estimate of the amounts of the two feldspars present in the perthites. Both Vogt's and Mäkinen's work will be referred to more fully beyond. Aside from Mäkinen's results there has been, so far as the writer is aware, no quantitative study made of these intergrowths which is at the same time both microscopic and chemical.

The importance of perthitic feldspars in many members of the granite and syenite families of rocks, and the lack of precise knowledge regarding them, is sufficient to indicate the importance of our having further quantitative information regarding them and has led the writer to attempt the present investigation. To anyone familiar with the characteristics of perthites and microperthites it will be obvious that data of a very precise character will be difficult to obtain. The coarser textured perthites of the granite pegmatites clearly offer a better chance of yielding quantitative results of greater precision than the finer microperthites of the granitoid rocks and were, therefore, made the subjects of a first attempt. The results are offered in the belief that they at least furnish a rather close approximation to the truth so far as the granite pegmatite feldspars are concerned, and the hope is entertained that they may, if applied with caution, throw some further light on the mode of origin of perthitic intergrowths in general.

With regard to the geological relationships of the pegmatites from which the perthites here studied have been taken, little can be stated at the present time. With the exception of the feldspar from Perth, Ontario, and perhaps that from Bedford, Ontario, the pegmatites are connected with an ordinary type of granite, one rather siliceous, low in lime, iron and magnesia, and relatively high in the two alkalies,

1 Tschermak's Min. u. Pet. Mitt., **24** (1905).

2 Die Granite Pegmatite von Tammela in Finnland und ihre Minerale, Bull. d. l. Commission Geologique de Finnlande, 1913.

potash predominating. The Bedford feldspar has apparently a similar relationship, though little is known about it; that from Perth is probably connected with some of the soda-rich magmas of Ontario.

Summary Description of the Structural Characteristics of the Feldspars Studied.— The microscopic characteristics of the perthitic feldspars are so familiar to mineralogists and petrographers and have been so often and so fully described, that it seems unnecessary to give a detailed description of the samples here studied. A few general observations will be made and a brief summary of some of their individual characteristics will be given.

The general form of the albite member of the intergrowth is most commonly that of relatively thin lamellae following a direction approximately parallel to the crystal plane, $\bar{8}01$. Other directions are sometimes followed, nor does the albite always form lamellae, but rather more or less flattened and irregular prismoid bodies. The crystal structure of the two members is, however, always substantially parallel.

In sections parallel to the base (001) the outcrop of the lamellae is in general roughly parallel to the edge 001–100. Taken in detail there are many minor curvings and changes of direction, and often very marked deviations may be noted. Perhaps the most common one is in a direction that appears to be in a direction parallel to that of a unit prism. Sometimes a single band will curve gradually around in this direction; again a number of short lamellae will coalesce along the same direction. In a recent paper A. F. Rogers [3] has called attention to intergrowths showing this characteristic, citing particularly a perthite from near Port Henry, N. Y., but referring also to that from Perth, Ont. The present writer has noted perthite with this feature developed in a quite striking manner in specimens from Haddam Neck, Conn., on which it was originally intended to carry out quantitative studies. There is a great variation in width in different samples and in the same sample. A single lamellae will also generally show much variation in this respect. They rarely exceed 2 mm. in width in any specimen and not very often 1 mm. The usual width is much less. The length of the bands also varies greatly even in the same specimen. They frequently pinch down and swell again, or pinch out entirely; branching and anastomosing are exceedingly common.

In sections parallel to the bracy-pinacoid the lamellae make an angle

[3] Jour. Geol., **21**, 5 (1913).

which is in the neighborhood of 70° with the basal cleavage. As a whole their direction is more uniform than in basal sections although more or less variation is to be seen, particularly in samples in which the albite bands are less numerous. The bands in general are more continuous and are probably less prone to branch and coalesce than in basal sections.

The contacts with the microcline are seldom smooth; generally they are irregular and sometimes finely serrated. Minute projections extend out from the band into the microcline following the principle cleavage directions, most commonly that of the base. These may in rare instances extend out for some distance or even to the next parallel band. Beside the main lamellae there is without exception a series of exceedingly minute lamellae which run parallel to the general direction of intergrowth. In some sections there is perhaps a gradation of these into the larger ones but generally they appear to be of a different order of magnitude. Much less commonly minute lamellae or flakes of albite may be seen following still other directions than those already mentioned, but these are unimportant.

In those perthites which are poorer in albite the lamellae appear in general to be more irregular in direction, distribution, width, and in form, than in those richer in albite. For the perthite from a given locality, however, the general features of the intergrowth taken as a whole are uniform and are quite characteristic.

In all the feldspars here studied the potassic feldspar is a microcline. In fact the writer has never yet seen a perthite which was not a microcline perthite, and doubts very much if there is such a thing as a pegmatitic perthite which contains orthoclase. Usually the characteristic polysynthetic twinning is present. In many cases it may be very faintly developed or missing altogether. This last fact may account for the statement, so frequently made, that the potassic member is orthoclase. It is worth noting in this connection that the potassic feldspar in many granitic microperthites shows the same characteristics, and also sometimes shows the albite twinning without the pericline. The optical properties are always those given for microcline so far as the writer's observations have extended.

A somewhat general peculiarity of these perthites is that cleavage surfaces are rarely perfectly continuous. Small variations of level may be noted from place to place. This slight deorientation has doubtless been caused by crushing stresses whose effect is also sometimes recorded in the slight deorientation of parts of the microcline (less commonly in the albite) in certain feldspars as seen under the

microscope in thin section. The albite is usually well twinned, though sometimes so minutely as to be hardly discernible. This feature renders the exact measurement of the extinctions difficult.

Remarks on the individual specimens: No. 1, from Perth, Ontario, Canada.— This specimen, from the original locality, is the richest in albite of any of the feldspars studied. It consists of a rather dark reddish-brown microcline intergrown with about an equal amount of a light red to almost white albite. The red color is due to the presence of exceedingly minute crystal scales of hematite which are chiefly contained to the microcline. They are usually arranged along definite crystallographic directions. Some hematite is found along fractures in the albite, or is more irregularly placed. It is estimated that there is about one-third as much of this material in the albite as in the microcline. The albite lamellae seldom exceed 1 mm. in width while a commonly observed width is 0.5 mm. The microcline bands will in general average broader than the albite. The orientation of the bands is fairly uniform parallel to the usual direction, but there is a common tendency to bend off toward the direction of the prism and often many short bands coalesce along this same direction. Pinching and swelling, branching and coalescing, often in a very complex fashion, are common particularly in certain areas. The albite forms minutely pointed surfaces of contact with the microcline as a rule. The microcline sometimes shows very distinct polysynthetic twinning but more often this is faintly developed and is often not visible at all. There is a slight alteration of the microcline to a fine opaque dust but on the whole it is quite fresh.

The extinction angles for the two feldspars are as follows:—

Microcline — on 001....16° to 17°
" — " 010.... 5°

Albite — " 001... 4.5°
" — " 010....19°

Specimen No. 2, Westfield, Mass., U. S. A.— Color white; perthitic structure not conspicuous. The microcline is practically devoid of structure as seen under the microscope. The albite lamellae rarely exceed 0.8 mm. in width, the majority running from 0.1 mm. to 0.3 mm.; they vary much in width along their length, pinching out and frequently forking at the ends. Besides the usual very minute lamellae running parallel to the general direction of intergrowth there is a set which makes an angle of about 12° with the basal cleavage in

010 sections. The microcline is quite fresh; the albite contains frequently minute vesicles. A few muscovite flakes were noted.

The extinction angles are:—

Microcline — on 001....18°
" — " 010.... 4.5°

Albite — " 001.... 3.7°
" — " 010....18°

Specimen No. 3, from Thirteen Island Mine, Bedford Township, Frontinac Co., Ontario, Canada.— The color is a light flesh red; perthitic structure can be seen only imperfectly although its presence is suggested by a lining seen most clearly on the 010 cleavage. The feldspar is, therefore, essentially a microperthite. The albite lamellae are very small, rarely exceeding 0.1 mm. in width and averaging considerably less. There is, however, a fairly sharp distinction in order of magnitude between the larger bands and the series of very minute lamellae which lie between them. The smaller series have the appearance of being more strongly segregated midway between the larger ones. The latter are quite irregular in direction and they commonly break up into several veinlets of smaller bands, or even into a series of lenticular bodies, which may coalesce farther on into a single band again. In some areas the structure is extremely complex and great care and patience had to be exercised in order to obtain accurate measurements. The microcline in the proximity of the albite bands frequently contains numerous minute specks or vesicles, some of ferruginous character. (Hence the red color of specimen.)

The twinning in the microcline, though very fine, is exceedingly perfect and beautiful; that in the albite is also very fine so that exact extinction measurements are difficult to make. Furthermore the extinction positions in the microcline in 010 sections are variable. This is probably due to a slight deorientation of the feldspar and is doubtless connected with the slight variations in the level of the cleavage surfaces, particularly noticeable in this feldspar. The extinction angles are:—

Microcline — on 001....17°
" — " 010.... 5° to 10°.

Albite — " 001.... 4° to 5° (average of several measurements made on broader twin lamellae).
" — on 010....17.8°

Specimen No. 4, from Mineral Hill, Delaware Co., Pa., U. S. A.— The color is slightly brownish to cream; only an indistinct lining indicates the perthitic structure so that this feldspar is essentially a microperthite. The albite bands are rarely over 0.2 mm. in width and range commonly from 0.05 mm. to 0.1 mm. They are individually quite irregular as to shape, continuity and direction, though taken as a whole they are uniform for this feldspar. A few deorientated crystals of albite were noted closely associated with the albite bands. Both feldspars are well twinned, particularly the microcline. A few well grown small crystals of muscovite are present; the alteration is very slight.

Extinction angles are as follows:—

Microcline	— on 001	16° to 17° on broader twin bands.
"	— " 010	6°
Albite	— " 001	3°
"	— " 010	19°

Specimen No. 5, from Pikes Peak, Colo., U. S. A.— Color a fresh light green; rather short albite lamellae are easily seen although the greater part of the albite is inconspicuous. The albite lamellae rarely exceed 0.6 mm. in width. They are sometimes of the usual elongate form, but more often they are short, irregular in outline and discontinuous, and are usually rather widely separated from one another. They often taper rapidly or may even terminate bluntly. They may follow for a short distance the usual direction of intergrowth and then turn off, apparently toward the direction of the prism. In 010 sections the lamellae appear in general to be longer but are also quite irregular, particularly as to width. Sometimes the position of a lamella will be occupied by a series of rather stout but small shreds. A few independently orientated albite crystals are present. Twinning is strongly developed in both members. The extinction angles are:—

Microcline	— on 001	17°
"	— " 010	5°
Albite	— " 001	3°
"	— " 010	19°

Specimen No. 6, from Grafton, N. H., U. S. A.[4]— White to almost

[4] The locality of this feldspar is not absolutely certain. It is from New Hampshire and probably Grafton.

clear in color; the albite lamellae are very clearly marked. They rarely exceed 0.6 mm. in width. The bands follow fairly well the usual direction although they frequently bend away from it. This is true also in the 010 sections where there is a rather unusual amount of departure from the usual angle of about 70° with the basal cleavage. A few independent albite crystals were noted. Both feldspars are strongly twinned. The structure of the microcline as seen in 010 sections is peculiar. Between crossed nicols the extinction is not uniform. There seems to be a sort of a fine lamellar structure developed with varying distinctness in different areas. This is often more distinct against a cleavage line where minute wedge-shaped lamellae, having different positions of extinction, are to be seen. The extinction angles vary from 1° to 7° but are never sharp. The impression is that there has been a slight deorientation of the feldspar following particularly along the general direction of the intergrowth which is substantially that of the Murchinsonite parting. It is probably here also connected with the slight variation in level observed in the main cleavage surfaces and has probably been caused by crushing movements in the pegmatite subsequent to its consolidation. The twinning in the albite shows also some irregularities of position. Extinction angles are:—

Microcline — on 001....17°
" — " 010.... 1° to 7°.

Albite — " 001.... 3°
" — " 010....17°

Quantitative Methods of Study employed; Microscopic.— The relative amounts of the two members of the intergrowths were determined by the well known micrometric method first described by Rosival. From a carefully chosen cleavage fragment of each feldspar to be studied, two very large thin sections were cut, one parallel to the basal, and the other parallel to the brachypinacoidal cleavage. These sections were especially prepared for the writer by the firm of Voigt & Hochgesang, of Göttingen, Germany, and no little credit is due to them for the exceptional quality and size of the sections. The measurements were all made with the large mechanical stage of Zeiss, which is superior to any other with which the author is familiar for measurements of this kind. The scales used were all carefully calibrated. In general the lines of measurement were run at distances of a millimeter apart.

The magnifications used were naturally varied according to the width of the particular lamellae in the section under measurement. With the basal sections particularly, it was found convenient to diminish the intensity of the illumination by lowering the condensing system and slightly raising the objective so as to bring out the contrast between the refractions of the two kinds of feldspar, thus clearly marking their respective boundaries. Crossing of the nicols was, however, constantly resorted to to make sure of the correct position of the boundaries. In the case of the brachypinacoidal sections it was in general found more convenient and quicker to measure with crossed nicols. Sometimes both the width of the microcline and albite bands were measured, but in general only the albite was measured, the microcline being determined by difference.

In order to obtain a true estimate of the accuracy of these measurements, the deviations of the individual measurements from the mean should have been found and the precision measure computed by the usual methods. Such a procedure involves a great expenditure of labor and is, in the present case, unwarranted because, however precise the results may be, there would still remain the rather considerable error (estimated to be probably ± 1 per cent) which arises from the fact that there are included within the microcline member many minute lamellae or stringers of albite impossible to measure exactly. There is also the impossibility, as will be pointed out later, of getting at the exact composition of the albite phase itself. It seemed, therefore, sufficient to choose as units, in judging the precision of the results of the micrometric measurements, the separate lines of measurement. Accordingly, in Table No. I are given for inspection, the total length measured for each section, the number of lines, their average length, and the average deviation from the mean of the volume percentages obtained from each line. The deviation of the mean itself from the true value is $\sqrt{n}$ times as probable as any single observation, n being the number of separate observations (here the number of separate lines of measurement). In the column headed A.D. are given the products $\frac{a.d.}{\sqrt{n}}$ for each feldspar measured. This indicates that, so far as errors of observation are concerned, the means are probably within one per cent of the true value. An estimate of the probable error (P. E.) by the usual formula, using the single lines of measurement as the units of observation, would have given slightly smaller values than those given under A.D., but the computation is hardly worth while in this instance. Inasmuch as the average width of a

Number and Locality	Orientation of Thin-section	Total distance measured in mms.	Number of lines measured.	Average length of line in mms.	Average deviation of single lines from mean % (a.d.).	Probable deviation of mean Percentage (A.D.).	Volume Percent of Microcline Bands (Mean).	Volume Percent of Plagioclase Bands (Mean).
No. 1 Perth, Ontario Canada.	|| to 001	504	20	25.2			54.68	45.32
	|| to 010	217.3	10	21.7			55.36	44.64
	Average of 001 and 010.	721.3	30	24.0	2.79	0.55	55.02	44.98
No. 2 Westfield, Mass. U. S. A.	|| to 001	446	16	27.9			81.20	18.80
	|| to 010	369	15	24.6			82.13	17.93
	Average of 001 and 010.	815	31	26.3	1.00	0.18	81.64	18.36
No. 3 Bedford. Ontario, Canada.	|| to 001	268.8	14	19.2			88.20	11.80
	|| to 010	299.8	15	20.0			85.60	14.40
	Average of 001 and 010.	568.6	29	19.6	1.53	0.28	86.90	13.10
No. 4. Mineral Hill, Delaware Co. Pa. U. S. A.	|| to 001	196.0	13	15.1			87.42	12.58
	|| to 010	212.4	10	21.2			87.73	12.27
	Average of 001 and 010	408.4	23	17.7	1.40	0.29	87.58	12.42
No. 5 Pikes Peak, Colo. U. S. A.	|| to 001	398.0	20	19.6			89.52	10.48
	|| to 010	305	14	21.8			87.50	12.50
	Average of 001 and 010.	703.0	34	20.4	2.9	0.57	88.51	11.49
No. 6 Grafton, N. H. U. S. A.	|| to 001	362	21	17.2			86.78	13.22
	|| to 010	516	17	30.5			89.65	10.35
	Average of 001 and 010.	878	38	23.0	2.6	0.40	88.22	11.78
No. 7	Härkäsaari, Tammela, Finland							
No. 8	Pakkalanmäki, Tammela, Finland							

TABLE I.

Results of micrometric measurements made to determine the relative amounts of microcline and albite in certain perthites from Granite Pegmatites; also relative amounts of the potassic and sodic feldspar molecules as calculated from the chemical analyses given in Table II.

Estimated % of volume of very minute bands of Plagioclase.	Total volume Percent & Microcline.	Total volume percent Plagioclase.	Percent by weight of Microcline bands.	Percent by weight of Plagioclase bands.	Specific Gr. used in calculation.[6]	%$KAlSi_3O_8$ calculated from Chem. Analysis.	%$NaAlSi_3O_8$ calculated from Chem. Analysis.	%$CaAlSi_2O_8$ calculated from Chem. Analysis.
2.0	53.02	46.98	52.3 [5]	47.7 [5]	2.57	51.9	45.8	1.5
2.0	79.64	20.36	79.2	20.8	2.55	73.3	25.7	1.5
2.0	84.90	15.10	84.6	15.4	2.56	76.9	21.5	1.2
2.0	85.58	14.42	85.3	14.7	2.55	80.4	18.6	1.4
2.0	86.51	13.49	86.2	13.8	2.55	80.6	18.5	1.7
2.0	86.22	13.78	85.8	14.2	2.55	77.4	21.7	1.35
			75.6	24.4		67.2	30.8	2.0
			72.3	27.7		71.1	27.3	1.6

[5] Corrected for FeO.

[6] The specific gravity used for the microcline was 2.62 for all; that given in the table is for the albite.

single lamellae in these intergrowths is well under 1 mm., and usually much under this figure, it is at once obvious that the total length of measurement made in each case exceeds by many hundred times the average length of a single lamellae.[7]

The presence of very small lamellae, often exceedingly minute, in the microcline member, having their general direction parallel to that of the larger ones, has been just referred to. In measuring each section the practice was followed of omitting temporarily the measurement of any lamellae that fell under two divisions of the scale used. After the section had thus measured an attempt to estimate the amount of these very small lamellae was made for each section. This was done by using a Zeiss 3 mm. apochromatic objective with the No. 12 compensating occular and a strong illumination. While only approximate estimates were possible, it is believed that the figure given in the table represents the true value for these lamellae to within ± 1.0 per cent.[8] This estimate, approximate though it is, is certainly better than a guess or than omitting them altogether from consideration as was done by Mäkinen.

In computing the weight percentages from those of volume obtained directly from the micrometric measurements, 2.62 was used throughout as the specific gravity of the albite member. This was the best value found for the albite in two of the samples by direct determinations with heavy solutions. For the microcline member slightly different values were used in some cases, as shown in the column headed Sp. Gr. In selecting these values we were guided by the specific gravity of the feldspar mixture as a whole. In the case of the feldspar from Perth, Ontario, for example, the specific gravity of the microcline is a little higher than the other because of the included hematite scales. There is, of course, some chance for error here but it cannot be as large as that introduced by the uncertainty regarding the true amounts of the very small lamellae referred to above, for a change of 0.02 in the specific gravity used would only effect a change in the second decimal place of the weight percentages.

---

7 No general rule for the length of measurements required for a desired accuracy such as was laid down by Rosival (200 times the length of the diameter of the average grain) can be adopted for measurements by this method in thin-sections or in general. The precision attainable must be estimated for each separate case by the usual methods applicable to such cases.

8 The writer feels reasonably sure that the error is in all cases a negative one for there are always a number of lamellae too small to be measured. The values for the different sections were so nearly constant, that in view of the error involved, it was deemed best to adopt for all what appeared to be the best value, viz. 2.0%.

The figures given for the various feldspars, of course, refer strictly speaking only to the particular fragment from which the thin-sections were cut, as do also the figures given for the chemical composition. No doubt, there exists some variation in the relative amounts of the two feldspars present in different feldspar fragments taken from the same pegmatite and even between different parts of the same large crystal. However, from the writer's observation on other smaller sections of these feldspars, as well as upon perthites in general, he believes that the samples here studied are quite representative of the

	1	2	3	4	5	6	7	8	9
	Perth, Ont. Canada	Westfield, Mass. U. S. A.	Bedford, Ontario, Canada.	Mineral Hill, Pa. U. S. A.	Pikes Peak, Colo. U. S. A.	Grafton, N. H. U. S. A.	Tammela, Härkäsaari.	Finland Pakkalanmäki.	Albite[9] from Grafton. N. H U. S A.
SiO_2	66.50	65.00	65.10	65.30	65.00	65.34	65.05	64.96	
Al_2O_3	18.40	19.50	19.13	18.83	19.21	19.08	19.19	18.91	
Fe_2O_3	1.05	.35	.32	.15	.20	.18	.28	.43	
MnO	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	
MgO	.07	.05	.06	.05	.03	.06	—	—	
CaO	.30	.30	.24	.28	.35	.27	.41	.32	
K_2O	8.77	12.36	12.98	13.60	13.62	13.05	11.19	12.09	1.78
Na_2O	5.40	3.03	2.53	2.20	2.20	2.56	3.57	3.31	9.98
H_2O	.20	.26	.16	.30	.12	.20	.15	.18	
Total	100.69	100.85	100.52	100.71	100.73	100.74	99.84	100.20	
Sp. Gr.	2.597	2.568	2.571	2.565	2.562	2.570	2.564		2.62

TABLE II.

Chemical analyses of alkali-feldspar intergrowths, Nos. 1–6 by Warren; Nos. 7 and 8, Eero Mäkinen; No. 9, analysis of albite separated from perthite by Warren.

run of the perthites or microperthites from granite pegmatites in general, and that, therefore, the results here given are equally representative.

Chemical.— The entire fragment remaining after the thin-sections had been cut was first very carefully crushed in a large flat-bottomed, chilled steel mortar, loss by the flying away of particles being guarded against. This material was then slowly ground in a screened, mechanically operated agate mortar. From this material the final sample

[9] Estimated to contain about 3 to 4 per cent attached microcline.

was taken for chemical analysis. The analyses may, therefore, be expected to represent fairly the same material upon which the microscopic measurements were made. The results of the analyses are collected in Table II, together with two by Mäkinen.[10] The figures for all of the radicals with the exception of the alkalies are the average of closely agreeing duplicates. The figures for the alkalies are in all cases but one [11] the average of three separate determinations. In estimating the alkalies the perchlorate method of separating the soda and potash was employed substantially as described by Gooch,[12] and was found to be very satisfactory, in fact, the writer prefers it for several reasons to the usual platinic chloride method. Blank determinations for alkalies were carried out under precisely the same conditions as the real determinations and furnished a slight correction which was applied.

The total amounts of the three feldspar molecules (Mic., Ab., An.) for each sample as computed from the analytical data are given in Table I.

In order to ascertain the amount of the potassic feldspar molecule actually present in solid solution in the albite member, a number of attempts were made by heavy solution separations to obtain the albite in a pure condition for analysis. As a matter of fact it was found extremely difficult to get anything like a clean separation of the two feldspars in most cases. After repeated trials it was found that by using acetylene tetrabromide diluted with benzene or xylene, the perthite from Grafton, N. H., could be made to yield an albite fraction that contained only a small amount of attached microcline. Careful microscopic measurements of the amount of microcline present, indicated that its amount could not be far from 3 to 4 per cent. As this material appeared to be the best that could be obtained, it was used for duplicate alkali determinations whose results are given in column 9, of Table I. In using these results to determine the amount of potassic feldspar in the albite an allowance was made for the presence of three per cent of the microcline as such. Such a calculation can, of course, be only approximate, nor is it possible to estimate the exact amount of the error. It seems likely, however, that the error is no greater than that introduced into the calculations from other sources, and it may be noted that this error is of about the same order as that intro-

10 Loc. cit., 66.

11 In this one, No. 5, one of the determinations was rejected as being obviously considerably too high for soda.

12 Methods of Analysis, F. A. Gooch, John Wiley & Sons, (1913).

duced by the error in the estimate of minute albite lamellae contained in the microcline, and there is an even chance, at least, that it may offset that error. It is necessary to assume that the amount of potassic feldspar dissolved in the albites of the other specimens is the same as in the one analyzed, and it was also assumed that the lime shown by the analyses, is all present in solid solution in the albite as the anorthite molecule. There appears to be very little likelihood of these two assumptions being far wrong. Making the assumptions noted above, the computation, from the data collected in Tables I and II, of the chemical compositions of the two mixed crystals which enter into the perthitic intergrowths is a simple matter. The results are given, culculated to 100%, in Table III, in which are also repeated in an abbreviated form a part of the data of Table II. Taking into consideration the various sources of error it is thought that the total error is certainly not greater than 2.0 units in the final figures for the mixed-crystal phases and is probably less.

Discussion of Results.— Reference to Table III will show that there is quite a jump from No. 1, the feldspar from Perth, Ontario, with 52.3 per cent of the microcline member to No. 8, the next nearest, with 72.3 per cent. The remaining feldspars show a distribution of values from 72.3 per cent to 86.2 per cent of microcline. Nos. 4, 5 and 6 are, however, quite close together, and admitting that the percentages given may be 1 per cent too high or too low, may be said to be practically identical so far as the relative amounts of the two members are concerned. A preliminary study of several other feldspars from other localities leads the writer to believe that these too would, if measured, fall within the range above given. As the feldspars studied are believed to be representative of granite pegmatite perthites in general, it is perhaps safe to say that such feldspars will most often be found to contain from 70 per cent to 87 per cent, approximately, of the microcline phase.

The amounts of the orthoclase and albite (plus anorthite) molecules as computed from the chemical analyses also show a considerable difference between No. 1 (Or. 51.9 per cent) and the next nearest, No. 7 (Or. 67.2 per cent). The rest lie nearer together. Omitting No. 1, the range of the remaining is from Or. 67.2 per cent to Or. 80.6 per cent, or 13.4 per cent.

It will be seen that the amount of $KAlSi_3O_8$ in the microcline falls between 93.0 per cent and 88.5 per cent (± 2.0). The variation appears to be greater than the estimated error and probably represents real differences of composition. The amount of Ab+An ranges between

		Perth, Ont. Can.	Westfield, Mass., U. S. A.	Bedford Ont. Can.	Mineral Hill, Pa. U. S. A.	Pikes Peak, U. S. A.	Grafton, N. H. U. S. A.	Härkäsaari, Finland	Pakkalanmäki, Finland	Vogts Orthoclase Mixed Crystal	Vogt's "Eutectic" Feldspar
		1	2	3	4	5	6	7	8	9	10
Micrometric estimates.	Microcline, % by weight	52.3	79.2	84.6	85.3	86.2	85.8	75.6	72.3		50.0
	Albite, % by weight	47.7	20.8	15.4	14.7	13.8	14.2	24.4	27.7		50.0
Calculated from chemical analyses.	Total % $KAlSi_3O_8$	51.9	73.3	76.9	80.4	80.6	77.4	67.2	71.1	72.0	42.0
	Total % Ab + An	47.3	27.2	22.7	20.0	20.2	23.0	32.8	28.9	28.0	58.0
Calculated from the micrometric and chemical data.	% $KAlSi_3O_8$ in Microcline Mixed Crystal	93.0	89.9	89.9	92.4	91.4	88.5			85–90	
	% Ab + An in Microcline Mixed Crystal	7.0	10.1	10.1	7.6	8.6	11.5			15–10	
	% $NaAlSi_3O_8$ in Albite Mixed Crystal .	89.5	87.1	87.4	85.9	84.5	86.9				
	% $CaAl_2Si_2O_8$ in Albite Mixed Crystal	2.9	5.1	4.9	6.5	8.0	5.4				
	% $KAlSi_3O_8$ in Albite Mixed Crystal	7.6	7.8	7.7	7.6	7.5	7.7				

TABLE III.

Table giving the mineral composition of the alkali-feldspar intergrowths as determined by micrometric and chemical analysis; also the approximate composition of the two mixed-crystal phases — microcline and albite types — as calculated from micrometric and chemical analyses. Columns 9 and 10 give Vogt's estimate of the composition of the mixed-crystal phases and of the "eutectic" feldspar mixture.

7.0 per cent and 11.5 per cent. The albite mixed-crystal shows about the same order of variation in the amounts of $NaAlSi_3O_8$. The anorthite variations are proportionally larger, the amounts of this molecule varying from about 3.0 per cent to 8.0 per cent. The writer, therefore, concludes that the microcline mixed-crystals of the granite pegmatite perthites will in general contain around 9.0 per cent of the albite phase in solid solution, and that the albite mixed-crystal contains about 8.0 per cent of the $KAlSi_3O_8$ molecule plus a small, but rather variable amount, 3.0 per cent to 8.0 per cent, of anorthite. The relative amounts of the orthoclase molecule and of the albite plus anorthite will in general be found to range from about 70–30 per cent to 80–20 per cent, though in exceptional cases much greater variations may occur, as No. 1 with 51.9 per cent of the orthoclase molecule present.

Discussion of the origin of Perthitic intergrowths.— It was formerly held by several mineralogists[13] that the perthitic intergrowths were formed by the introduction of albite from without into previously formed microcline crystals. This view is probably now entertained by few. While there are undoubted instances where albite has been introduced from without by later mineralizing action along cleavage or fracture lines, or by more irregular replacement about the margins, there is usually in such cases, independent evidence in the surrounding rock that such action has been going on. In the case of the great majority of perthitic intergrowths, at any rate, such evidence is lacking. It is difficult to see how albite could be introduced into the microcline so uniformly and extensively, with the perfect preservation of the microcline's structure, if the openings, along which the former was introduced, were prepared by a breaking of the original microcline. Furthermore, such breaking could hardly be effected by any form of crushing without a general deorientation of the fragments, nor is it likely that the microcline crystal could be ruptured in such fashion by any sudden change of volume incident to a possible passage through an inversion point. Anyway fracturing of the microcline would most likely follow along the more important directions of weakness, the principle cleavages, and these directions are not those followed by the albite growths. It also seems improbable that the albite could have worked its way into the microcline along lines of easy solubility by a replacement process. If such were the case we should expect to find the replacement more marked about

13 In this connection see particularly O. Wenglein, Inaug. Diss. Kiel., (1903).

the marginal parts of the crystals. Instead we fine that a striking feature of such intergrowths is the uniformity of the albite distribution taken as a whole throughout the entire crystal. We should also hardly expect that a wholesale replacement such as would be represented by the case of feldspar No. 1 (47.7 per cent Ab.) could be effected without causing a profound dislocation, or even a complete breaking up, of the original microcline crystal structure. It seems necessary to abandon this theory, particularly as the one given below offers an entirely reasonable explanation of the observed facts and is in keeping with the physico-chemical theory relative to such systems.

J. H. L. Vogt [14] appears to have been the first to definitely formulate a physico-chemical theory to account for the origin of the perthitic intergrowths. As a result of an extensive statistical study of the chemical data regarding the compositions of the feldspars which were first to crystallize from rock magmas of different composition, he was led to conclude that the alkalic feldspars, orthoclase and albite (plus some anorthite), formed a broken series of mixed-crystals with a eutectic point between them. He estimated that the two mixed-crystal phases had the approximate composition, Or, 72 per cent; Ab + An, 28 per cent, and Ab + An, 88 per cent; Or, 12 per cent (Points *i* and *q* on the diagram, Fig. IV). He was also led to conclude, judging, among other things, from their rough constancy of chemical composition and their structure, that the so-called "cryptoperthites" described by Brögger and others,[15] represented a eutectic mixture [16] — a simultaneous crystallization of the two mixed-crystals — and that the eutectic composition lay in the region Or, 40–44 per cent; Ab + An, 60–56 per cent or approximately Or, 42 per cent; Ab + An 58 per cent (Point E, Fig. IV). He furthermore pointed out that, in all probability with lowering temperatures (and perhaps also only under considerable pressures) a change would occur in the chemical compositions of the mixed-crystals, due to diminished solubility of the components and also, probably, to the occurrence of an inversion point in the potassic feldspar from an α to a β modification, viz.— from orthoclase to microcline. He estimated the chemical compositions of the finally resulting crystals of microcline to be in the neighborhood

14 Loc. cit.

15 Zeit. fur. Kryst. u. Min., **16**, 537.

16 It of course does not follow that the cryptoperthitic feldspars represent the only form which the feldspar eutectic can assume. Separate crystallizations of the two members might form under certain favorable conditions. A fine grained aggregate or an intergrowth would perhaps be the most probable form to result from such a mixture. See later regarding this point.

of Mic. 85–90 percent; Ab + An, 15–10 per cent. The albite set free by such a change — unmixing — might be expected to withdraw more or less completely from the microcline, and orientate itself in positions such as those occupied by the albite lamellae in the perthite intergrowths. This unmixing would also doubtless coarsen the texture in the case of the cryptoperthite feldspars.

The present writer believes that there is little doubt but that in the compositions of the homogeneous alkali-feldspar phenocrysts of our effusive or intrusive rocks we have evidence that the potassic and sodic feldspars form what amounts to a continuous series of mixed-crystals. He has also pointed out in the case of the alkaline-granites and their associated cover rocks of porphyritic texture, occurring in the region of the Blue Hills and Quincy, Massachusetts,[17] that, whereas, in the relatively quickly chilled (quenched) porphyries, the phenocrysts are, or were originally, a homogeneous soda-potash-feldspar, in the underlying and more slowly cooled granites, the feldspars, of substantially the same composition, are a microcline-microperthite. It was also pointed out in the paper alluded to, that the phenocrysts of the porphyries were easily altered and recrystallized, wholly or in part, and appeared to have been generally quite unstable as originally formed. The conclusion was drawn that the alkali-feldspars probably form at relatively high temperatures a complete series of homogeneous mixed-crystals, but at lower temperatures, probably as a result of an inversion, they formed a broken series of mixed-crystals with a eutectic point, as was proposed by Vogt. The phenocrysts would, therefore, represent the earlier formed phase caught in the rapidly chilled and consolidated magma and prevented from unmixing by the great inertia to molecular rearrangements characteristic of the solid state — an unstable phase in other words. The granitic feldspars on the other hand, crystallizing under more favorable conditions to the adjustment of equilibria, underwent the unmixing more or less completely, and being crystallographically very similar, finally crystallized in parallel position as a perthitic intergrowth.

The writer suggested that the feldspars might first crystallize as a series of mixed-crystals belonging to type I of Rooseboom's classifications of binary systems. Dittler[18] has offered on the other hand experimental evidence to show that these feldspars belong to type III of Rooseboom's classification, viz. a continuous series of mixed-crystals

17 These Proceedings, **40**, No. 5, 317–323 (1913).

18 Dittler, E. Die Schmeltzpunktkurve von Kalnatronfeldspathen, T. M. P., B. B. **3**, 513–522 (1912).

having a minimum melting point. He determined the melting intervals of some nine soda-potash feldspars ranging in composition from Or., 6.0 per cent to Or., 67.6 per cent, the majority of them lying in the range Or., 40.0 per cent to 50.0 per cent. The melting intervals were determined upon crushed material under the microscope by the method of Doelter. To the writer the data given by Dittler are not conclusive. The number of points determined seem rather too few; and in view of the very considerable errors that are associated with this method of melting point determination, fully pointed out by A. L. Day,[19] it seems doubtful if Dittler's melting intervals have much significance.

Mäkinen,[20] following Vogt, has also expressed the opinion that the perthites are the result of an unmixing, and suggests an analogy in the behavior of the system NaCl–KCl studied by H. Brand.[21] He has also pointed out that the unmixing process must have taken place somewhat above the temperature 575° C.[22] He finds that in the Tammela pegmatites, muscovite has clearly replaced the feldspar after the albite bands were formed, and as this muscovitization took place during the pneumatolitic period, during which only α quartz was formed, the temperature of the albite crystallization is at least fixed above the inversion temperature of the quartz, viz. above 575° C.

Further consideration of the problem of the relations of these feldspars has led the writer to abandon the idea suggested by him in a former paper and above referred to, that the soda-potash feldspars of the porphyries represent a series of mixed-crystals having a definite range of stability at relatively high temperatures. This assumption leads to serious difficulties when one attempts to apply it to the crystallization of the ordinary granites which are characterized by the presence of the two feldspars separately crystallized, difficulties from which the theory put forward by Vogt is in large measure free. In its general features the latter seems to the writer to be well in accord with the observed facts and to lend itself well to the interpretation of the textural relations of the two feldspars as they occur in their rocks.

To account for the development of the homogeneous alkalic feldspars which are intermediate in composition between the two mixed-crystal phases of Vogt, anorthoclase etc., it seems sufficient to the author to consider them as entirely metastable crystallizations. They represent the first crystallizations of feldspar from a magma chilled

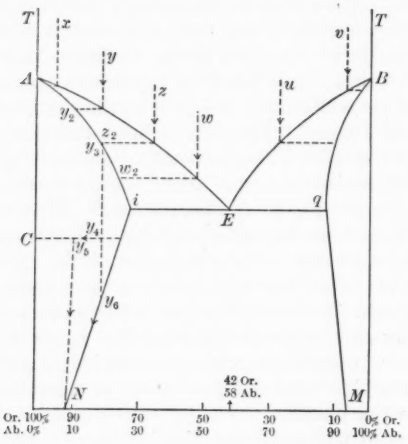
19 Fortschrift der Min., Kryst, u. Pet. **4**, 134–137 (1914).
20 Op. cit. 75.
21 Neues Jahr. für Min. Geol. u. Pal., **32**, 638 (1911).
22 Op. cit., 74.

with relative rapidity. It seems reasonable to suppose that the two alkalic feldspars, at least, possess, in the neighborhood of their crystallization interval, a strong tendency to crystallize together in all proportions on account of the close similarity in crystal structure and volume which characterize them. The rate of the process which tends to separate them into two types of mixed crystals, one potassic and the other sodic, is probably a slow one, possessing relatively little energy, much less rapid and energetic than the tendency of the two feldspars to crystallize from the rapidly chilled and probably undercooled magma. Under such conditions the latter tendency dominates and the two feldspars crystallize together either as a homogeneous (so far as can be told) crystal or as an exceedingly fine intergrowth (cryptoperthite). Once formed in this fashion, though in a metastable condition, the inertia of the solid state, doubtless especially great in substances like these, indefinitely postpones further change in the direction of the establishment of a true equilibrium, and the crystals often persist as formed. The case is quite different when a longer period of time is allowed for crystallization, as in the case of the magmas which consolidate at relatively deeper levels or even in the case of the groundmass of the porphyries.[23] Here we would have slower cooling, less undercooling, and probably also more abundant liquid or vapor phases. The separation of the two mixed-crystal phases can then take place with less or greater perfection according to the perfection of the equilibrium adjustment permitted by the rate of cooling and other conditions. The result would be either the formation of a perthitic or microperthitic intergrowth, or, under still more favorable conditions, of separate unorientated crystallizations of the two phases.

The process of feldspar crystallization may be further considered with the aid of a diagram representing the kind of equilibrium which is believed to hold for these minerals. The diagram, Figure IV, is substantially that used by Vogt. The true position of the curves is of course not known but the various points on the eutectic line and along the base may be considered as located approximately. The positions of the points N and M have been located in accordance with the figures obtained for the compositions of the mixed-crystals in the present investigation, and lie at or somewhat outside Vogt's lower estimate (about 10% of Or.) for the corresponding points. The points *i* and *q*

23 See in this connection the description of the groundmass feldspars in the Blue Hill porphyries, Op. cit., 249 and 322.

have been located in accordance with Vogt's estimate, at 72% and 12% of orthoclase respectively, which represents probably a fair approximation to the truth. Assuming that the diagram represents in a general way the conditions of equilibrium for the crystallization of these feldspars, it is evident that if we start with a melt having a composition represented by a point lying well to the right of *i*, say Or. 95% (composition *x*), we should have, as the temperature fell to ordinary temperatures, represented by the base line, assuming of course that equilibrium was established throughout, as a final product, a homogeneous mixed-crystal of the microcline type of the same



composition with which we started. If we start with a mixture say of the composition represented by a feldspar like No. 4 with about 80% Or. (composition *y* on the diagram), crystallization would begin when the curve AE was reached and the composition of the first crystallization would be that of the point y_2. Assuming a continuous adjustment of equilibrium as crystallization progressed, the composition of the solid phase would change continuously along the line A*i* until a composition y_3 was reached when the whole mixture would become solid. With still further lowering of temperature, if we assume that at some temperature, say at that represented by the point C, an inversion of the orthoclase to microcline occurred, then when the temperature

of the solid reached this temperature at y_4 there would occur a sharp change in the composition of the solid crystals and we should have formed a crystal phase of the composition represented by the point y_5, a microcline mixed-crystal, and simultaneously a certain amount of an albite mixed-crystal would separate out. The composition of the microcline crystal would then change along the dotted line until N was reached; the albite phase would change along qM. If there was no sharp inversion point then the mixed-crystals, y_3, would persist until the point y_6 was reached when an unmixing would begin with the formation of a microcline mixed-crystal whose composition would then change along the line iN until N was eventually reached, and an albite mixed-crystal of a composition represented by corresponding points on the line qM. The composition of the albite would eventually be that of the point M. The albite phase set free by such an unmixing, inasmuch as it takes place in the solid state, would not in all probability escape to any extent from the original crystal, but rather would withdraw in some more or less regular manner and crystallize within the microcline. As the two phases are closely similar in crystal structure and volume, the unmixing is perhaps in the nature of a parallel shifting of the units of crystal structure throughout the space of the original crystal, and the two finally become fixed in parallel orientation as the familiar perthitic intergrowth. We can easily imagine conditions, such as rapid cooling, under which the inversion and unmixing process would not take place, or take place imperfectly, and there might then result homogeneous orthoclase crystals containing all of the 20% of albite, or a crystal containing anyway less of the intergrown albite phase than that which would have formed had the equilibrium been completely established throughout. The fair degree of constancy in composition exhibited by the two mixed-crystal phases as deduced in the present investigation on the pegmatitic perthites, indicates that the unmixing approaches in these, at least, a fairly definite end point.

If we start with a melt of a composition represented by the line z, crystallization would begin when the temperature had fallen to the curve AE with the formation of a crystal of the composition z_2. This would change continuously along the lower curve until the point i was reached when crystals of composition q would also begin to form, and these two mixed-crystals would then continue to grow until the solidification was complete. A similar procedure would obtain for a mixture, say of composition w, the only difference being that there would be formed a larger proportion of crystals of composition q rela-

tive to those of composition *i*. Further lowering of the temperature would result in an unmixing, either gradually along the lines *i*N and *q*M or with a break at temperature C, with the development of a perthitic intergrowth, just as has been explained previously.

If we assume that the equilibrium is not continuously adjusted during the first crystallization interval, as perhaps might be expected in the case with magmas whose earlier crystallizations formed with relative rapidity, developing phenocrysts of some size, it seems probable that, in the case of mixtures like *w*, for example, zonal growths might be developed — alternative crystallizations of the two phases of variable composition — until the solidification had been completed. The results of some such crystallization as this are probably represented by the zoned feldspar of many granites of coarsely porphyritic habit as, for example, certain phases of the Rapakiwi (Finland) granite and those from near Jonesport, Me., U. S. A. At lower temperatures the unmixing would occur in amount corresponding to the particular compositions of the different zones. With relative rapid cooling, probably accompanied by undercooling as in the case of the porphyries, metastable mixed-crystals might be formed, at least during the earlier part of the period, and these would later unmix more or less completely forming intergrowths.

From a melt having the composition of the eutectic a similtaneous crystallization of the two mixed-crystals of compositions *i* and *q* would result, and while these might, under very favorable conditions, develop as separate crystallizations, it seems much more probable that intergrowths would result. Furthermore, undercooling would be much more probable to occur in the case of melts of eutectic composition. The amount of the undercooling and the resultant effect on the rate of crystallization and the equilibrium adjustment would doubtless determine whether a homogeneous metastable mixed-crystal, or a cryptoperthite, or perhaps a perthite would form. In any case further cooling of the solid crystals would tend to bring about an unmixing which would change the metastable mixed-crystals into an intergrowth, or coarsen any intergrowth already formed, the full or partial accomplishment of such a process depending on local conditions. Moreover mixtures of compositions near to the eutectic, perhaps even somewhat removed from it, would in all probability behave in much the same manner, particularly where rapid cooling obtained, and little or no distinction could be made between the final products so far as structure is concerned. The general structure of the cryptoperthites and their approximation to a constancy of chemical composi-

tion lends support to the idea of a eutectic composition. It will be evident, however, from what has just been said that the occurrence in a rock of richly perthitic feldspars is by no means an indication that such intergrowths are necessarily of eutectic composition, or even very near it, as appears to have been held by some petrographers.

Mixtures of a composition like that represented by the line *u* may be supposed to result under certain conditions in the so-called antiperthite intergrowths, while a mixture of composition *v*, well to the left of the diagram, would yield finally a mixed-crystal of the albite type of the same composition as that with which we started.

From what has been said above it will be clear that rapid cooling, accompanied probably by undercooling, is believed to be primarily responsible for the development of anorthoclase, cryptoperthite and the perthitic intergrowths generally, where the latter are relatively rich — above something like 28 per cent Ab. Inasmuch as the rate of cooling is dependent on the geologic position in which a magma consolidates, it follows that the presence of such feldspars are an indication that the rocks containing them have consolidated relatively near or at the surface. If this is correct it is a point of some importance. The anorthoclase phenocrysts of many of our porphyritic rocks bear out this contention, and geologic evidence is by no means lacking that many occurrences of rocks characterized by the presence of richly perthitic or cryptoperthitic feldspars have reached relatively high levels in the earth's crust, for example, the alkaline rocks of the Christiania region and the microperthitic rocks of eastern Massachusetts, particularly of Quincy and the Blue Hills, not to mention many other examples that come to mind.

We also believe that microcline is the stable phase of the potassic feldspar. The tendency to invert to microcline, like the intimately associated tendency of the two mixed-crystals to unmix, is probably not a strong one, and may often not find conditions favorable to its accomplishment. The change may be suspended indefinitely and even not occur at all, or not until the necessary energy is supplied by long continued heat and pressure such as might result from metamorphic processes. That microcline is of much more common occurrence than is generally supposed, the writer firmly believes. It is probably true that many students of rocks when they do not see the characteristic "grating" structure in a potassic feldspar call it orthoclase, overlooking the fact, if they were ever aware of it, that microcline does not always, in fact rather frequently, does not show this structure, that it may show only the albite twinning, or no twin-

ning at all. The writer has studied a number of rocks in which orthoclase was described as being present only to find, on careful study, that the alleged orthoclase was really microcline.

In comparing the feldspars of the pegmatites with those of the granites with which they are connected genetically, or of different granites, it is of course impossible, with the rather meager data now at our command, to estimate definitely the effect of constituents other than the feldspars which are present in the respective magmas on the equilibrium relations existing between the feldspars. The effect of varying pressures is also largely of unknown magnitude. In the case of granite magmas, relatively poor in anorthite and mafic minerals, the principle differences in chemical composition as compared with the pegmatitic magmas which are derived from them, are generally considered to be the greater amounts of water or water vapor and other of the more volatile constituents — mineralizers — of the pegmatitic magmas. The presence of greater amounts of water would probably have the effect of collecting different relative amounts of the two feldspars in the one as compared with the other. Probably with the greater excess of water in the pegmatitic magma would go a relatively greater amount of the more soluble (under those conditions) feldspar molecules. That the excess water would have any great effect in modifying the general relations of the two feldspars during crystallization in the pegmatites as compared with the granites, the writer very much doubts. One effect of larger amounts of water etc. would very probably be to facilitate any adjustment of equilibrium that might be imminent, particularly where the adjustment had to take place in the solid state. In the pegmatites the possible presence of more active residual liquors in contact with the crystals might conceivably have the effect of carrying the unmixing somewhat further in the direction of extracting more of the more soluble phase. As this is probably the albite, it may be, that in the pegmatitic feldspars, such as those here studied, the microcline phase contains a somewhat lower percentage of the albite than is the case for corresponding feldspar in the granites. The differences in the two cases are, in the writer's opinion, likely to be rather slight at least so far as the main crystallizations of pegmatites and granites in general are concerned. The residual liquors in all cases would carry some feldspar in solution along with other materials, and in special cases, perhaps considerable amounts. These liquors might segregate centrally or otherwise, or migrate, and in any case would finally deposite their dissolved material as separate crystallizations, distinctive in character, of albite and microcline or, under cer-

tain conditions, of albite or microcline alone, perhaps of a composition very near to that of the pure end members of the system. Such, probably, are the crystallizations which we find about the pockets or elsewhere in certain pegmatites.

We feel therefore justified, at least for the purposes of discussion, in assuming that the same general relations obtain between the potassic and sodic feldspars during their crystallization in the pegmatites as in the granites, and in looking upon the figures here obtained for the chemical composition of the two mixed-crystal phases, from a study of the pegmatitic perthites, as holding true, approximately of course, for the granitic feldspars. Much further work must be done on the feldspars and their rocks before the problem can in any way be looked upon as settled, but it is believed that the theory elaborated above may at least serve as a reasonable working basis.

Summary.— The results of a micrometric and chemical study of six specimens of perthitic feldspars from granite pegmatites are recorded. To these have been added the results of a similar study by Mäkinen of the perthites from the granite pegmatites of Tammela, Finland. Preliminary studies of certain other perthites are also referred to. Taken together the feldspars studied represent widely separated localities and quite a diversity of composition. It is believed that they may be considered representative of the perthitic feldspars of granite pegmatites in general.

The methods of study employed and the characteristics of the intergrowths are briefly described. The quantitative results are collected in three tables which show the chemical compositions of the various feldspars studied, the relative amounts of the two mixed-crystal phases which constitute them and the chemical composition of each of these phases. These results and their probable precision are briefly discussed.

The older theory that the perthitic structure is due to the introduction of albite from without into a previously formed microcline or orthoclase crystal is discussed and held to be untenable. The more recently proposed theory of Vogt that the potassic and soda-lime feldspars form a broken series of mixed-crystals with a eutectic point between them is discussed with particular reference to the alkalic members and is held to offer a satisfactory basis on which to explain their relationships so far as these can be judged from such evidence, chemical and petrographical, as is at present available. The progress of crystallization in mixtures of various composition is considered with the aid of a diagram, a), for the case where a perfect and continu-

ous adjustment of equilibrium with falling temperature is assumed to obtain, and, b), for the case where more or less hindered or imperfect equilibrium is supposed to obtain, chiefly as the result of relatively rapid cooling such as might happen in the case of magmas consolidating at, or relatively near, the surface.

It is concluded that, as held by Vogt, the perthitic structure found in primary potassic feldspar where the amount of albite (plus a little anorthite) does not exceed say about 28%, is due to the unmixing of a previously homogeneous mixed-crystal. Where more considerable amounts are present it is held that the particular texture which results, whether intergrowth or separate crystals, is very largely determined by the rate of cooling, particularly during the period of initial crystallization. Relatively rapid cooling is held to favor in general the development of perthitic structures, or in extreme cases, of homogeneous mixtures — metastable forms. The presence of such crystallizations in a rock is therefore held to be an indication of the relative conditions of cooling, and therefore of the relative geologic position in which the rock magma consolidated.

It is held, that while the total composition of the perthitic feldspars of the pegmatites may differ somewhat from those of the granites, the general relations of the two feldspars during crystallization will be much the same in both cases, and that the final composition of the two mixed-crystal phases in both the pegmatites and the granites is approximately represented by the figures found by this investigation on the pegmatitic feldspars.

It is held that microcline is the stable phase of potassic feldspar at relatively low temperatures, including ordinary temperatures, and that its presence in rocks is much more general than is commonly supposed: its failure to appear is due to a feeble tendency to invert, permitting the inversion interval to be readily passed by under certain conditions.

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